UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

BUREAU OF COMMERCIAL FISHERIES, Donald L. McKernan, *Director*

SONIC TRACKING OF ADULT SALMON AT BONNEVILLE DAM, 1957

BY JAMES H. JOHNSON

FISHERY BULLETIN 176
From Fishery Bulletin of the Fish and Wildlife Service
VOLUME 60

PUBLISHED BY U.S. FISH AND WILDLIFE SERVICE • WASHINGTON • 1960

PRINTED AT THE U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. - Price 20 cents

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U. S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9—35239*

Library of Congress [59r55b1]

CONTENTS

ABSTRACT

Adult salmon bearing miniature sonic transmitters were tracked individually in the forebay of Bonneville Dam. Fish were tracked as far as 10 miles upstream and for periods ranging up to 16¾ hours. In the release area adjacent to the dam, the fish seldom swam more than 50 feet away from shore or remained away from it for more than 2 minutes at a time. After leaving the dam most fish followed the shoreline near which they were released; they rarely swam in water more than 30 feet deep. During daylight the average speed at which they traveled over the bottom was 1.5 miles per hour, and their net rate of movement upstream was 1.2 miles per hour. Each of the three fish tracked from daylight into darkness slowed its pace or ceased swimming as darkness deepened.

SONIC TRACKING OF ADULT SALMON AT BONNEVILLE DAM, 1957

By JAMES H. JOHNSON, *Fishery Research Biologist*
BUREAU OF COMMERCIAL FISHERIES

A more detailed knowledge of individual fish behavior in the immediate vicinity of dams is needed for the conservation of the Pacific Northwest salmon runs. Upstream migrants arriving at dams during periods of high river flow face serious delays in locating fishway entrances, or physical injury, or both, in the violent turbulence of spillway discharge. After a high flow period on the lower Columbia River in June 1955, large numbers of dead salmon were collected below Bonneville Dam by biologists of the Oregon Fish Commission. Exactly where and how these fish died is not known. But assuming that at least part of the mortality was the result of unsuccessful attempts to pass beyond the dam, the question arises whether it occurred primarily while the fish were seeking entrance to the ladders, or whether large numbers of fish were swept back through the spill gates after emerging from the ladders.

Knowledge of fish movements immediately above and below existing dams is meager. It was obtained largely from the estimated effectiveness of various fish-collection systems and from visual observations limited by turbidity and hydraulic conditions. Conventional marking and tagging studies in the vicinity of dams provide average rates of movement from the release point to the point of recovery, but yield no information concerning fish movements between these points. As a method was clearly needed to overcome these limitations, special sonic equipment to track continuously the movements of individual fish was developed by the U.S. Fish and Wildlife Service. This equipment was first used to study the general behavior pattern of adult salmon in the forebay of Bonneville Dam.

During the late summer and fall of 1957, upstream migrants were tagged with sonic fish tags and their movements were precisely tracked in the Bonneville forebay. Individual fish were tracked as far as 10 miles upstream and for periods as long as 16¾ hours. Although we have been limited thus far to working above the dam and under reduced river flow conditions (see fig. 1), we

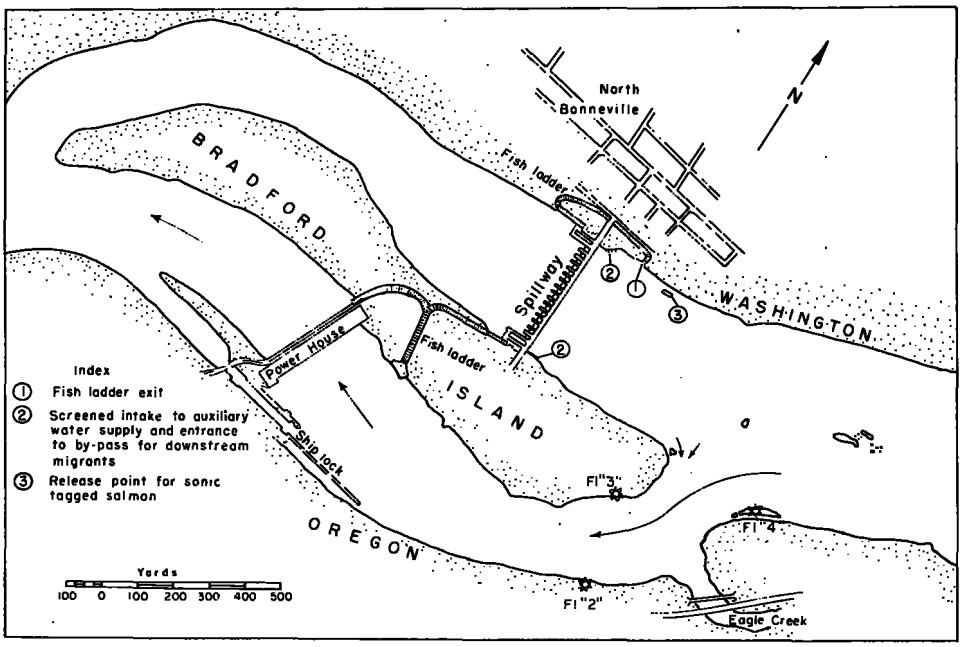

FIGURE 1.—Bonneville Dam. Fish were tracked during late August, September, and October, while the spillway was closed and the river flow was channeled entirely through the powerhouse.

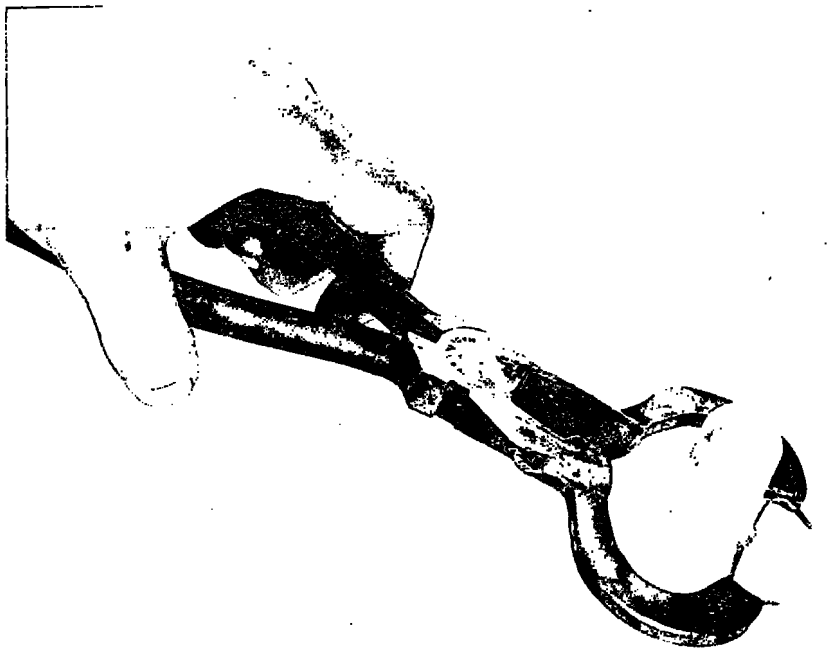

FIGURE 2.—Sonic tag held with tool used to attach the tag to the fish. The tag is activated prior to being used by twisting two protruding wires together.

believe the data presented will, with further observations obtained by the same method, contribute appreciably to our knowledge of fish behavior at dams.

We wish to thank the U.S. Army Corps of Engineers, Portland (Oregon) District, for permission to work in the vicinity of Bonneville Dam, and the Oregon Fish Commission for their assistance in trapping the fish.

This study was directed by Parker S. Trefethen and Dr. Gerald B. Collins of the Fish and Wildlife Service, Seattle Biological Laboratory; tracking was performed by John R. Pugh, John C. Mason, and the author.

MATERIALS AND METHODS

Equipment

Sonic equipment used to track individual fish includes a sonic tag and a special receiver mounted in a boat. The sonic tag, attached to a fish, transmits sound waves which are picked up by the receiver; an observer may thus record the position of the fish in relation to the boat.

The transmitter is contained in a thin aluminum capsule approximately 2.5 inches long and 0.9 inches in diameter (fig. 2). Soldered to each capsule is a nickel-chromium wire "hog-ring" with sharp points for attaching the tag to a fish. The capsule contains battery-powered miniature electronic components, forming a transistorized oscillator which drives a resonating crystal cemented in one end of the capsule. Electronic components and capsule, coated with waterproof plastic, plus the attaching device, have a combined weight of 0 to 2 grams when immersed in water. Operating on a carrier frequency of 132,000 cycles per second with a pulsing rate of 1,000 to 2,000 cps., the tag transmits ultrasonic sound waves in all directions through the water with a usable range up to 800 feet. The expected life of the sonic tag used at Bonneville was 8 hours, although some lasted much longer.

The signal from the tag (fig. 3) is picked up by a receiver tuned to the tag's frequency. This unit is incorporated with an echo-ranging system (a modified Minneapolis-Honeywell Regulator Company "Sea-Scanar") to form an instrument which automatically tracks the sonic tag and indicates its position in relation to the receiver. The sonic-tagged fish appears as a "blip" of light on a cathode-ray tube viewing screen, calibrated to give direct readings of the bearing and distance of the

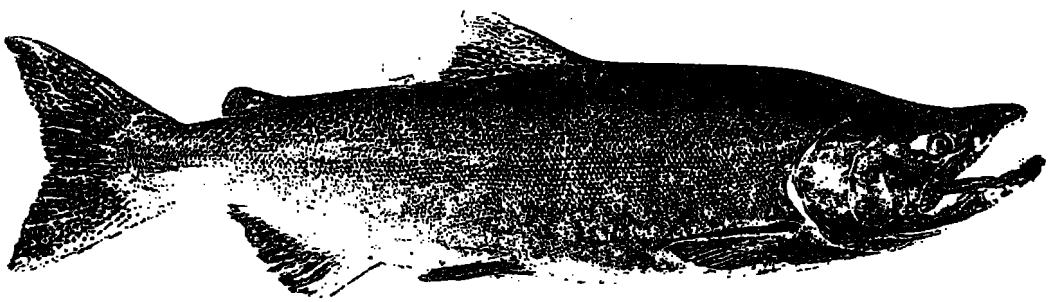

FIGURE 3.—Sonic tag attached to adult chinook salmon.

fish from the receiver. A tilt-angle meter which shows the vertical angle at which the signal is being received from beneath the surface makes it possible to calculate the depth at which the fish is swimming. More detailed descriptions of the sonic equipment are given by Trefethen (1956), and by Trefethen, Dudley, and Smith (1957).

At Bonneville the automatic receiver was mounted in an 18-foot boat (fig.4). The equipment was powered by a 110 volt a.c. gasoline generator.

Tagging and tracking procedure

Fish were obtained from the Washington-shore fish ladder at Bonneville Dam. As the fish emerged from the ladder, they swam into a large floating trap operated by employees of the Oregon Fish Commission engaged in a separate tagging program. This trap was towed 100 yards upstream to a raft which was anchored 50 feet offshore. A single fish was quickly transferred by dipnet from the trap to a live box 4 feet long, 2 feet wide, and 2½ feet deep. Some fish were tagged immediately; others were held in the live box as long as 2 hours before tagging (table 1). Open at the top, the live box was raised until the back of the fish was approximately an inch beneath the surface of the water. As soon as the fish momentarily stopped moving, with special pliers (fig. 2) a sonic tag was fastened in place behind the dorsal fin (fig. 3). The lid was then fastened shut and the live box completely submerged. After an additional holding period of approximately 20 minutes a vertical slide gate in one end of the live box was raised and the fish was free to swim out.

Our crew waited 50 to 75 feet away in the boat with the tracking gear in operation, ready to follow the fish up or down stream as it emerged from the live box. Each fish was tracked until we lost the

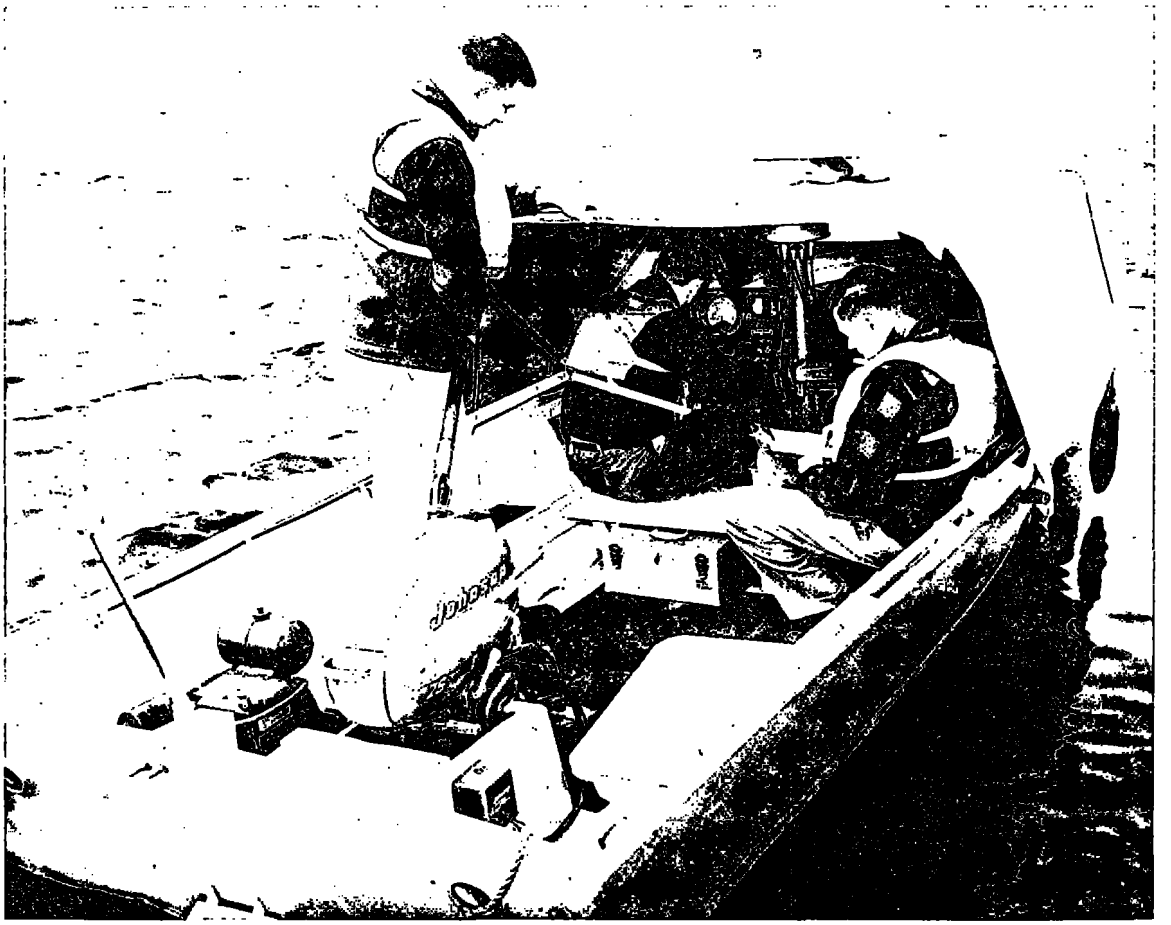

FIGURE 4.—Sonic equipment and crew in position aboard the fish-tracking boat.

signal, and an additional hour usually was spent searching the area, trying to reestablish contact. Sufficient supplies were carried each day to operate for periods up to 20 hours if necessary.

A three-man crew was required to operate the equipment and record the observations. Their duties were as follows: One man operated the boat and tended the power supply for the sonic equipment; a second operated the sonic equipment and signaled instructions to the boat operator to keep the tagged fish within range; the third recorded data on the location of the fish as determined by the sonic gear operator, and also maintained a log of the position of the boat. This was done by descriptive notation (e.g., "time 1232—beneath Bridge of the Gods, 30 feet off Washington shore") and by taking cross-bearings with a sighting compass on river navigation markers, land points, islands, bridges, and other fixed landmarks along shore.

RESULTS

Fish movements in the release area

Of the 43 fish tagged and released, 37 were fall run chinook salmon (*Oncorhynchus tshawytscha*); the 2 silver salmon (*O. kisutch*) and 4 steelhead trout (*Salmo gairdnerii*) listed in tables 1 and 2 were tagged on days when chinooks were unobtainable.

We considered the release area to be that part of the forebay which extends 500 yards above the spillway. The area is bordered on the north side by the Washington shore and on the south by Bradford Island. Safety regulations did not permit our boat to approach closer than 300 yards to the dam until flow through the spillway was reduced to approximately 15,000 cubic feet per second. This condition channels the river flow almost entirely down the south side of Bradford Island through the powerhouse and leaves the forebay area for a quarter of a mile above the

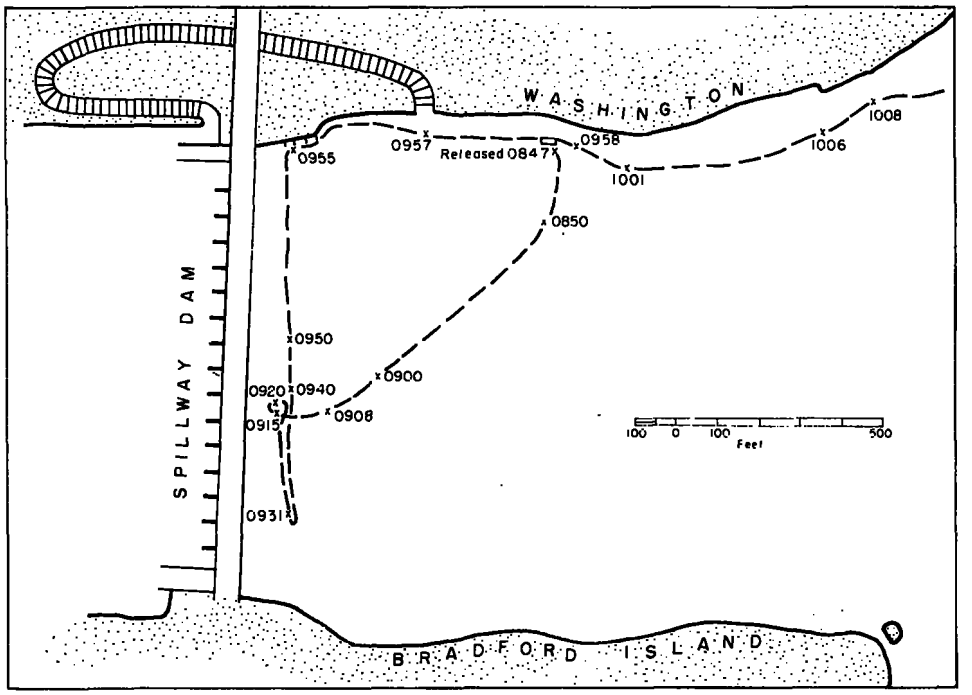

FIGURE 5.—Movements in release area of fish tracked on September 3, 1957, in Bonneville Dam forebay (see also fig. 10).

spillway relatively free of strong currents. From August 23 until observations were completed, all (18) of the main spill gates were completely closed. The only remaining flow through the release area was that drawn off by the Washington-shore fish ladder (about 200 cfs.) and by 2 screened fishway auxiliary water-supply intakes (fig. 1). Current velocity at these 3 points was less than 2 feet per second and decreased to near zero within a few yards outside of the intakes. During this period, after August 23, the general area in which the fish were released resembled a lake more than a river.

The plots shown in figures 5, 6, and 7 are representative of movements of the fish which were observed in the release area. A fish tracked on September 8 (fig. 6) was typical in that it remained close to the Washington shore, repeatedly reversed its course up and downstream, and finally began to swim steadily upstream an hour after release.

Sixty-two percent of the fish swam no farther than 50 feet from the Washington shore while moving about within the release area. Fish that left the Washington shore usually kept close to the face of the spillway or Bradford Island or quickly returned to the Washington shore. Fish tracked in the release area spent more than 90 percent of a total of 47 hours swimming within 50 feet of one of these three boundaries. With 5 exceptions fish did not spend more than 10 minutes at any one time away from shore and were seldom away from it as much as 2 minutes at a time.

The average swimming speed for these fish in deep water (0.9 m.p.h.) was almost twice as fast as near shore, with the added difference that offshore they moved continuously but inshore frequently stopped swimming.

Some fish moved out of the release area in less than two minutes; others remained there as long as 4 hours and 50 minutes before moving out. One fish still remained in the area when contact was lost nearly 5 hours after release (table 1). The average time spent by fish in the release area was 1½ hours.

Suspecting this "move-out time" might be dependent on size of fish, or length of holding period, or both, we examined by multiple regression the contribution of these factors to the time the fish took between release from the live box and the beginning of sustained upstream movement. While the contribution of size was negligible, the contribution of time held was significant at the 10-percent level. Thus it appeared that fish held

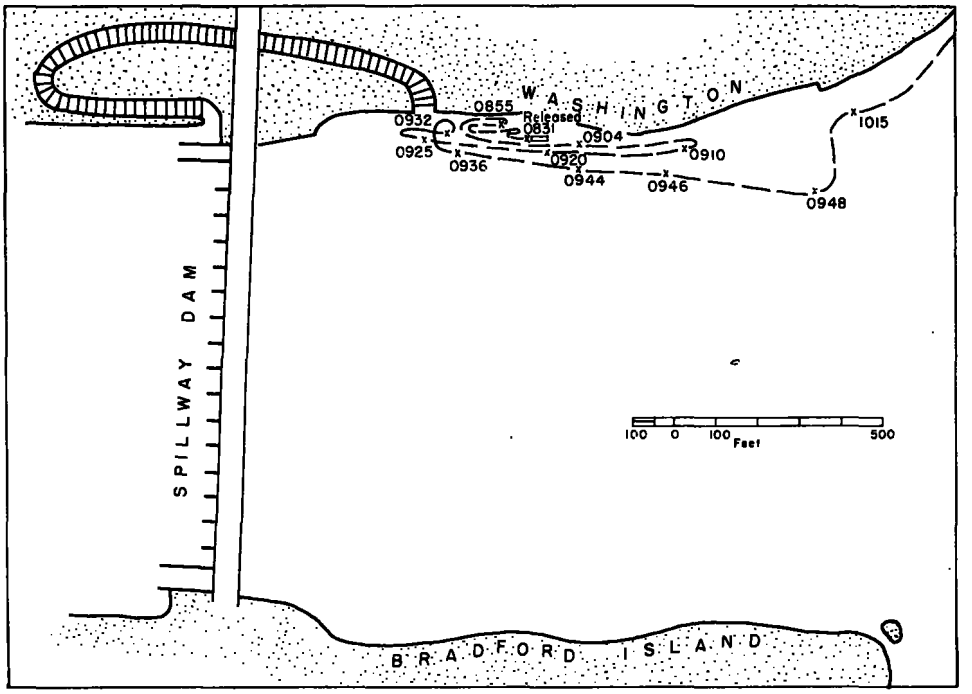

FIGURE 6.—Movements in release area of fish tracked on September 8, 1957, in Bonneville Dam forebay.

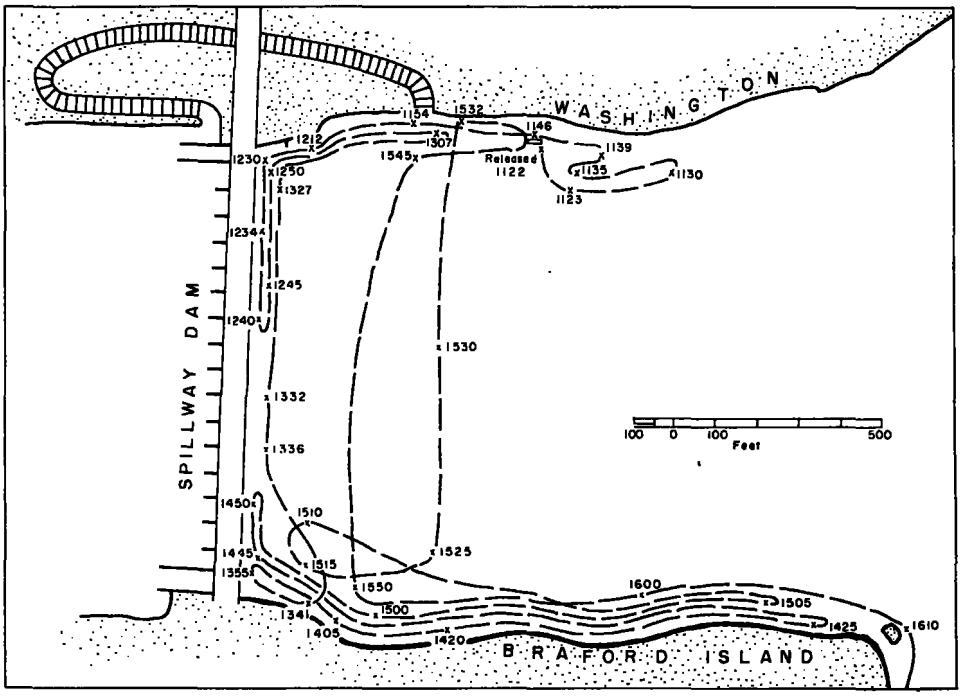

FIGURE 7.—Movements in release area of fish tracked on September 18, 1957, in Bonneville Dam forebay. Fish crossed powerhouse channel to Oregon shore and entered Eagle Creek.

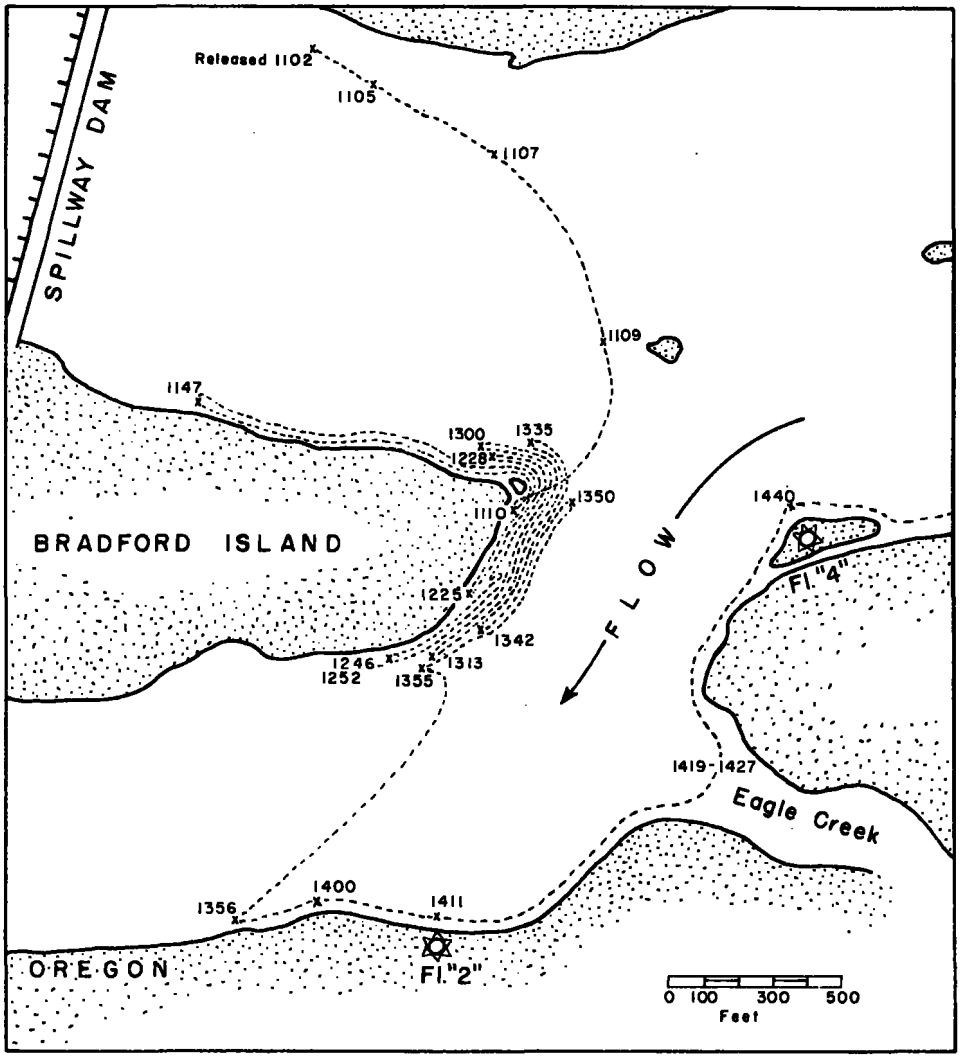

FIGURE 8.—Movements of fish tracked in the release area, forebay of Bonneville Dam, September 13, 1957 (see also fig. 12).

longer in the live box moved out of the release area sooner.

The fish tracked September 3 (figs. 5 and 10) was one of nine that swam downstream to within 50 feet or less of the spillway. Seventy percent of the fish tracked moved some distance downstream from the release point before returning upstream, or before contact with them was lost.

The fish tracked September 18 (fig. 7) made more crossings at the spillway (3½) and also traveled farther (2.8 miles) than any other fish before leaving the release area. The average distance traveled within the release area was slightly more than one-half mile. In this wandering prior to moving out, the fish did not appear to show any particular interest in the three water-intake points (fig. 1). Occasionally a fish would pause for a minute or two in front of one of these screened intakes, but much more often swam past without slowing.

The performance of the fish tracked on September 13 (figs. 8 and 12) was especially interesting. Halfway across the spillway forebay it appeared to be heading directly toward the mouth of Eagle Creek on the Oregon side. As it came into the current above the tip of Bradford Island, however, it veered sharply to shore, then began to swim in a series of arcs around the tip of the island. The plot in figure 8 is diagrammatic in that the fish actually maintained

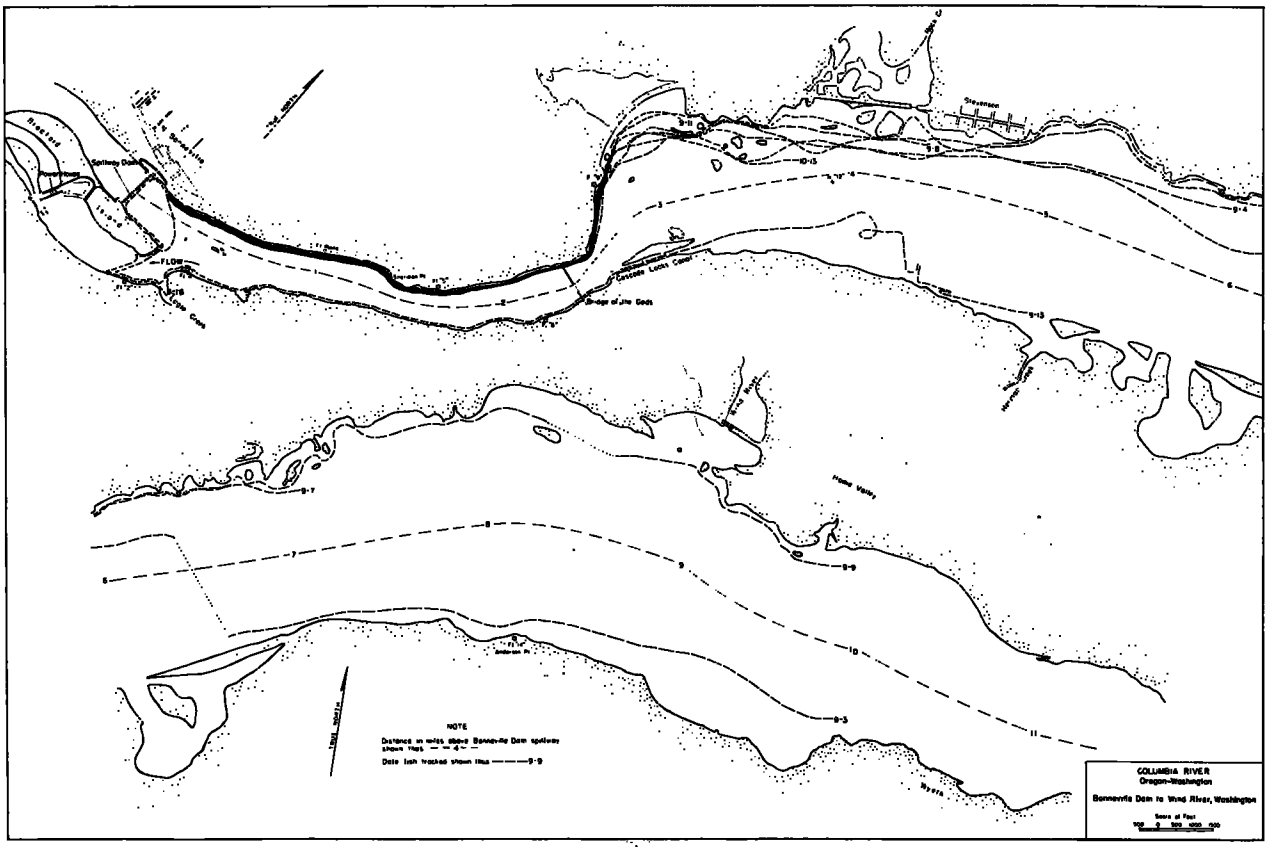

FIGURE 9.—Composite plot of 23 fish tracked out of release area, Bonneville Dam, 1957.

a constant distance, 15 to 30 feet offshore on the current side of the island and 40 to 60 feet offshore on the spillway side, from the time it arrived at the island until it departed, except for six or seven traverses when it ventured as much as 50 feet into the current, but returned quickly each time. These abortive dashes offshore made it appear that the fish was eager to continue upstream but perhaps reluctant to leave the reference point provided by the island shoreline. When it finally did break away it swam or drifted more than 500 feet downstream with the current before arriving at the Oregon shore. It immediately began moving upstream, again keeping within 20 feet of the shoreline.

We were able only intermittently to obtain readings of the exact distance of fish from the boat, and so were seldom able to calculate their exact depth. In water less than 30 feet deep along shore where the fish generally stayed, the instrument readings frequently indicated that fish were swimming so close to the bottom as to blend into the echo, and thus failed to return a distinguishable blip on the cathode-ray-tube viewing screen. The blips we recorded, representing 22 fish, placed them at all depths from surface to bottom.

Farther offshore, in water as deep as 100 feet, the 8 fish on which positive blips were recorded were seen most frequently between 5 and 25 feet beneath the surface; 40 feet was the greatest depth at which any fish was seen. Some may have been lost by descending deeper. The sonic tag was unable to withstand pressures encountered below approximately 50 feet. The tag now in use has a thicker wall capable of withstanding pressure at a depth of 200 feet. Tag failure due to leakage is the most likely explanation of the loss of contact with a number of fish immediately following their release.

Fish movements above the release area

Twenty-three fish were tracked for some distance above the release area, and once they had left the area their movements became strikingly uniform. This is shown clearly in figure 9,

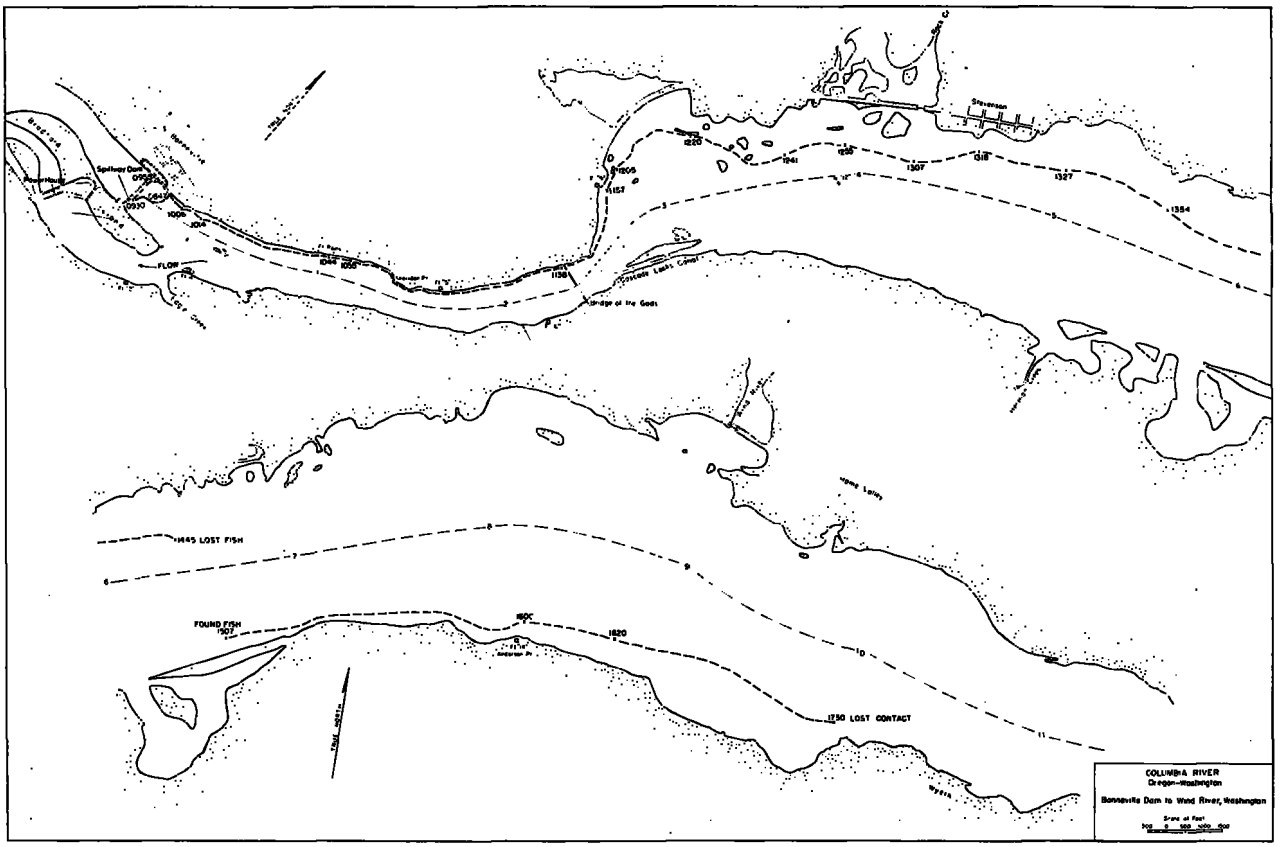

FIGURE 10.—Course of fish tracked September 3, 1957, Columbia River (Washington-Oregon), Bonneville Dam to Wind River, Washington.
Miles upstream from Bonneville Dam spillway indicated by: -- 4 ---
Course of fish and hour of day (military time) indicated by: --- x ---
1035

particularly through the constricted 2-mile section of river between the release area and the Bridge of the Gods. Bottom contour lines superimposed on figure 9 would show that, having left the area, sonic-tagged fish seldom crossed over the 30-foot contour line into deeper water. Between the release area and the Bridge of the Gods, the bottom drops off sharply along both sides of the river, which may account for the fish usually traveling within 10 to 25 feet of shore as they swam through this section.

Above the Bridge of the Gods, fish that followed the Washington shore continued to swim close to the bank consistently until they had passed navigation marker F9. Here they came into extensive shallows (depths of less than 20 feet) for the first time since leaving the dam, and the routes of individual fish began to vary. However, the general pattern continued—that of fish remaining within water not more than 30 feet deep.

The average rate of movement also remained nearly constant. The 9 fish tracked above the Bridge of the Gods averaged 1.51 m.p.h., from the release area to the bridge and 1.47 m.p.h., from that point. These averages are based on the total distance traveled over the bottom by each fish during hours of daylight. Calculated on a river-mileage basis (see figs. 9–14), the average net speed above the bridge decreases to 1.21 m.p.h. In the general course followed by fish along the Washington shore, current velocities also averaged slightly less above the Bridge of the Gods than below it. These velocities ranged from 2 feet per second to less than ¼ foot per second. We estimated the actual swimming speed of several fish (speed over the bottom plus speed of the opposing current) at 3.5 to 4.0 miles per

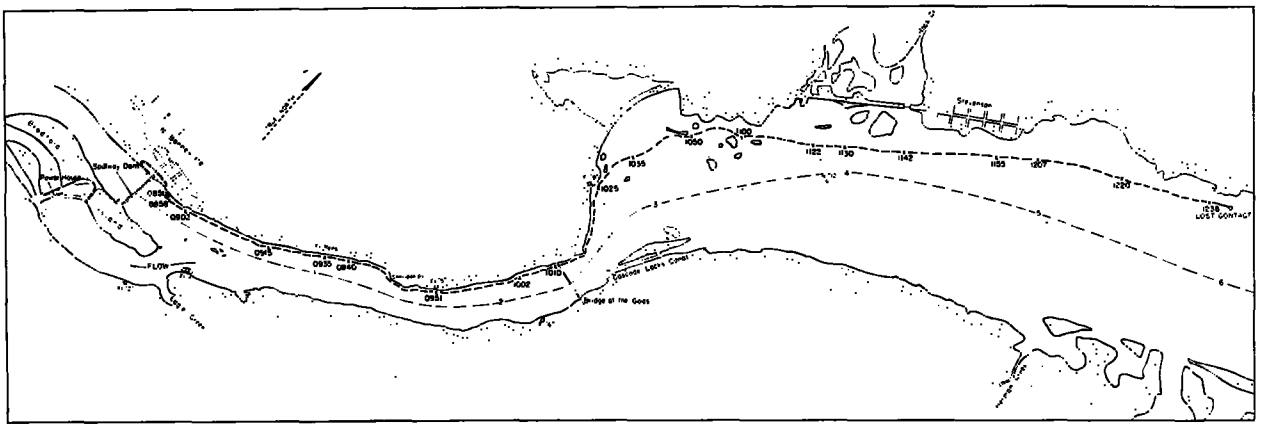

FIGURE 11.—Course of fish tracked September 4, 1957, Columbia River (Washington-Oregon), Bonneville Dam to Herman Creek, Oregon.
Miles upstream from Bonneville Dam spillway indicated by: -- 4 ---.
Course of fish and hour of day (military time) indicated by: --- x ---
1010

hour for short distances while they were swimming against current velocities of 1½ to 2 feet per second.

In traveling the 9 miles from Bonneville to Wind River, fish that followed the Washington shoreline traveled roughly a mile farther than if they had kept to deep water in midchannel, or 1¼ miles farther than they would have, had they followed the Oregon shore.

Three chinook salmon were tracked from daylight into darkness, and each evening as it grew dark the fish either slowed their pace or came to a complete halt. The comparative rates of movement were as follows:

Date	Before dark	After dark
1957	(*M.p.h.*)	(*M.p.h.*)
Sept. 9	1.29	0.42 (fig. 14)
Sept. 13	0.98	.06 (fig. 12)
Oct. 6	.17	0

One fish tracked on September 9 (fig. 14) gradually slowed its pace until it was barely making headway. At the same time (1935 hours) it became necessary to use a flashlight in taking notes. A short time later, the fish stopped moving. One hour and 15 minutes later, the fish began to swim again, and on the final mile its

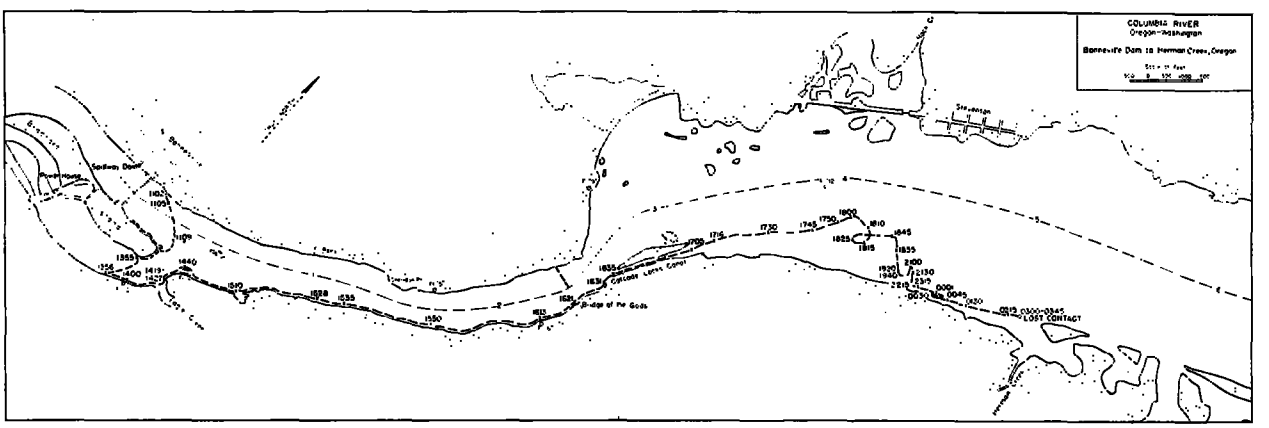

FIGURE 12.—Course of fish tracked September 13, 1957, Columbia River (Washington-Oregon), Bonneville Dam to Herman Creek, Oregon.
Miles upstream from Bonneville Dam spillway indicated by: -- 4 ---.
Course of fish and hour of day (military time) indicated by: --- x ---
1550

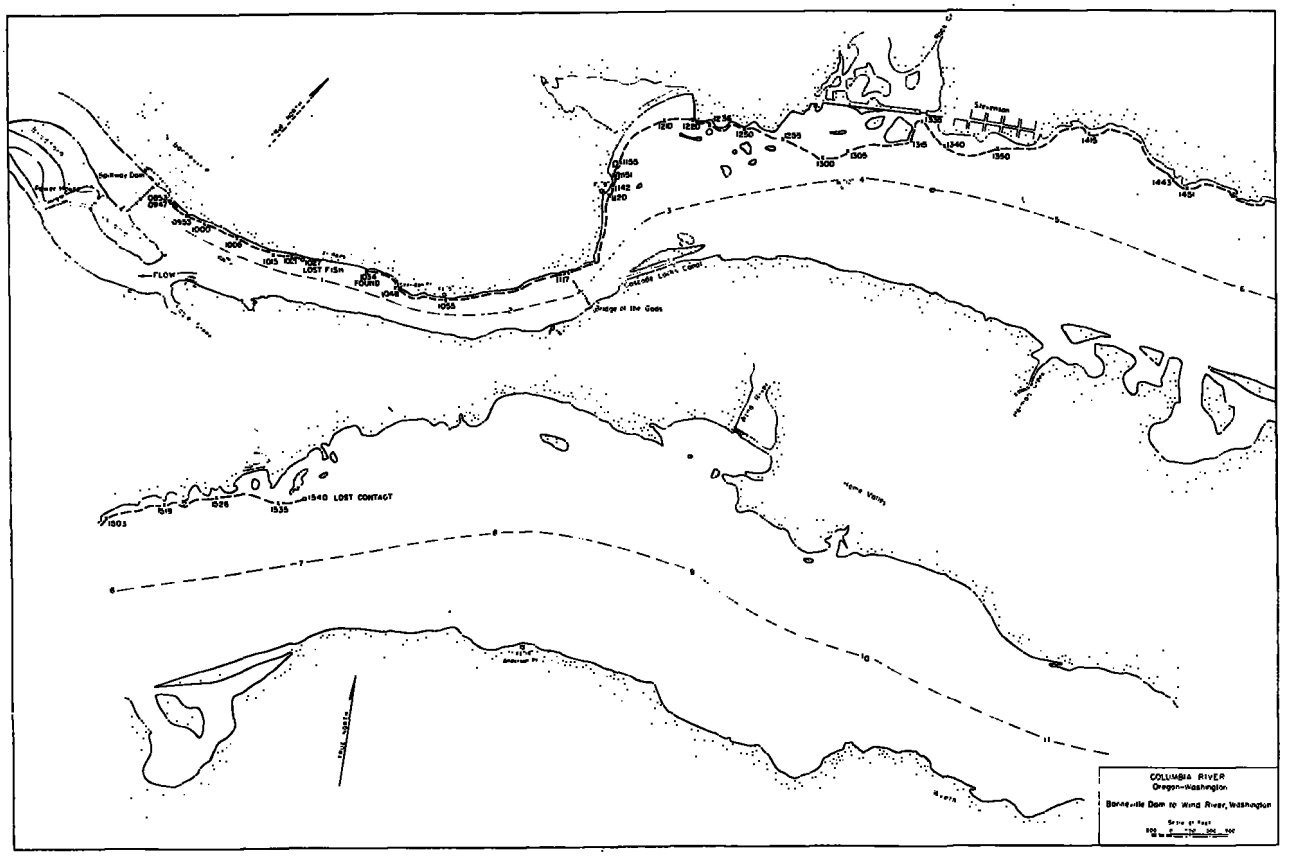

FIGURE 13.—Course of fish tracked September 7, 1957, Columbia River (Washington-Oregon), Bonneville Dam to Wind River, Washington.
Miles upstream from Bonneville Dam spillway indicated by: -- 4 --.
Course of fish and hour of day (military time) indicated by: --- x ---
1055

average speed was 1 mile per hour. The fish resumed upstream movement less than 5 minutes after the moon rose full from behind a mountain.

The net distance upstream traveled after dark by the September 13 fish (figs. 8, 12) was one-half mile. During the 8½ hours of darkness the fish alternated between moving up and downstream over short distances at a very slow rate of speed and remaining in one spot for periods ranging up to 1 hour. At times it moved neither up nor downstream, but moved slowly toward or away from shore.

Only one fish crossed the river above the release area (fig. 10). Contact with it was lost for 22 minutes and was not regained until some time after the fish had reached the Oregon shore. The other two fish that crossed to the Oregon side did so in the vicinity of the dam. One made its way sporadically 200 yards into Eagle Creek, stopped, and was in the same spot 2½ hours later at dark, when it had to be abandoned (figs. 7 and 9). The fish tracked September 13 nosed into the mouth of Eagle Creek but left within 8 minutes. It was delayed 20 minutes more a short distance above the creek mouth by apparent reluctance to pass underneath or around a large river tow boat tied along shore with engines idling. Once past this it swam steadily upstream until it arrived at the old Cascade Locks ship canal, no longer in use since the completion of Bonneville Dam. The fish hesitated several minutes before entering this 100-foot wide concrete channel and once inside moved slowly the length of it, pausing frequently, and keeping mostly to the middle. Two dozen or more sport fishermen were fishing from the banks of the canal at the time.

Extending downstream from Sheridan Point over a distance of approximately one-half mile,

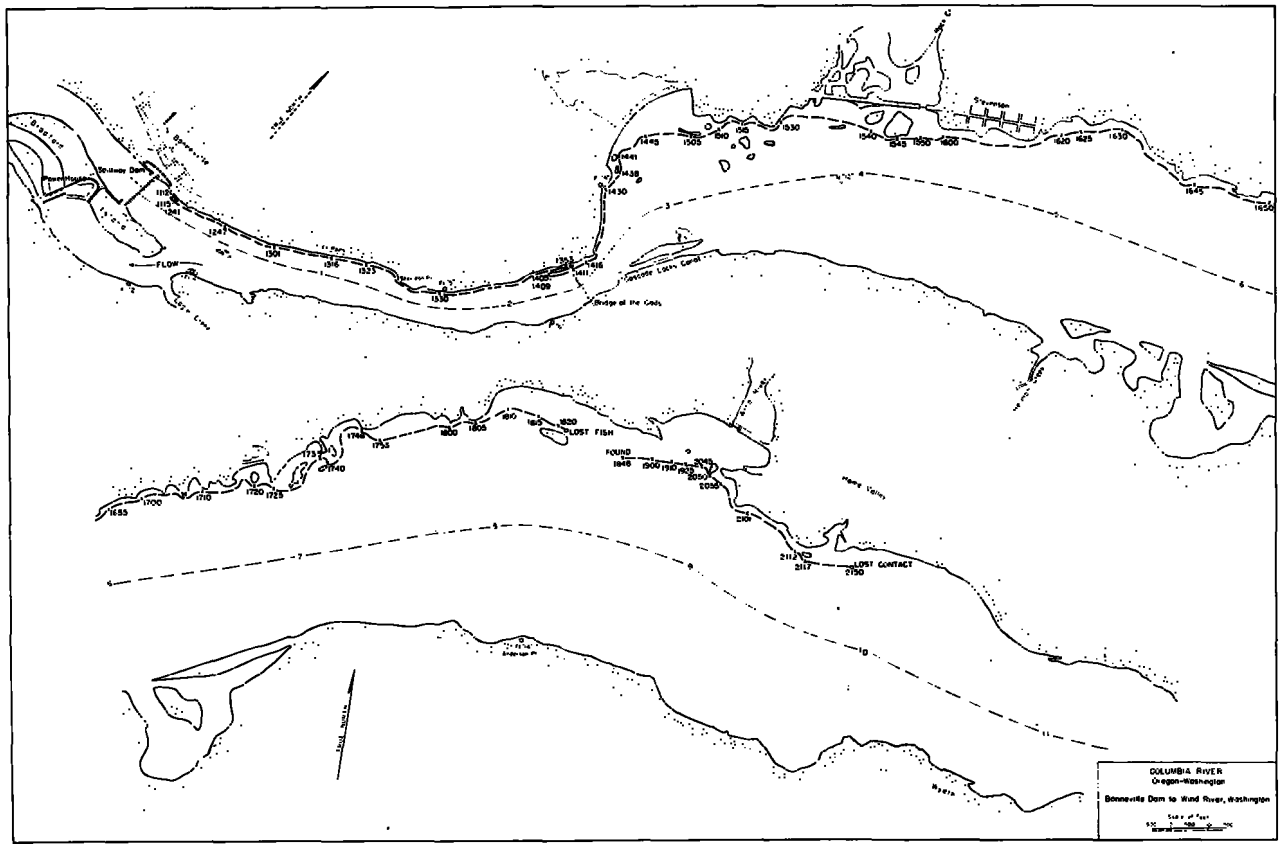

FIGURE 14.—Course of fish tracked September 9, 1957, Columbia River (Washington-Oregon), Bonneville Dam to Wind River, Washington.
Miles upstream from Bonneville Dam spillway indicated by: -- 4 ---.
Course of fish and hour of day (military time) indicated by: --- x ---
1810

log rafts were tied along shore, in some places extending 400 feet or more into the river. Fish that had previously been swimming upstream at a steady rate usually slowed or stopped completely within a few yards after passing underneath the rafts, then moved slowly and erratically upstream with frequent pauses and occasional back tracks until the rafts were cleared. The fish then resumed the faster steady rate observed before the rafts were encountered. This was the only point above the release area where back tracking was common. Underneath the rafts fish were likely to travel downstream several hundred feet with prolonged pauses at the turning points, but elsewhere the back tracks were rarely as much as 100 feet and the return upstream was more likely to be immediate. One exception was the fish tracked September 9 which moved back 700 feet at the Bridge of the Gods. It was not unusual for fish to slow their pace or pause momentarily before passing under the bridge, where the supporting concrete piers created considerable turbulence.

DISCUSSION

The migration pattern of fish in the release area and the pattern of their journey upstream was studied. Because the effects on fish as a result of handling and tagging are difficult to determine, and because some if not all of any resulting impairment presumably diminishes with time, we believe that the movements of fish once they are well underway upstream are probably more nearly representative of their natural behavior than movements during the period prior to their moving out. Comparatively, their movements within the release area were more diverse than were their movements farther upstream, although this behavior might also be true of untagged fish.

TABLE 1.—*Release record of sonic-tagged fish tracked at Bonneville Dam, 1957*

Date (1957)	Species	Fish length inches	Time held in live box		Time spent in release area		Total number hours tracked	
			Hours	Minutes [1]	Hours	Minutes	Hours	Minutes
Aug. 8	Steelhead	27	17	0	-------	5	3	3
14	Chinook	36	1	0	-------	[2] 1	-------	1
14	do	38	1	30	-------	[2] 1	-------	1
15	do	36	2	30	-------	[2] 1	-------	1
15	do	34	-------	30	-------	[2] 1	-------	1
16	do	32	-------	30	-------	[2] 55	-------	55
19	do	30	1	0	-------	[2] 1	-------	1
20	Steelhead	28	1	0	-------	[2] 1	-------	1
20	Chinook	33	1	30	-------	9	-------	56
21	Steelhead	28	2	0	-------	[2] 12	-------	12
22	Chinook	20	2	0	-------	40	1	39
23	do	34	1	30	-------	[2] 10	-------	10
23	do	36	-------	45	2	14	2	31
26	do	36	1	30	-------	[2] 1	-------	1
27	do	34	2	0	1	[2] 22	1	22
28	do	32	2	0	-------	[2] 22	-------	22
29	do	34	1	45	-------	28	1	10
29	do	42	-------	45	-------	59	2	0
30	do	36	1	0	-------	[2] 54	-------	54
30	do	38	1	0	-------	[2] 9	-------	9
Sept. 3	do	25	1	30	1	8	8	45
4	do	30	1	30	-------	1	3	49
6	do	32	-------	45	-------	[2] 3	-------	3
7	do	34	1	45	-------	49	6	42
8	do	34	1	0	1	13	5	4
9	do	30	1	5	1	[2] 5	1	5
9	do	36	-------	30	1	30	10	38
10	do	32	1	30	-------	20	-------	49
11	do	32	-------	30	-------	54	3	44
13	do	28	-------	30	2	57	16	43
18	do	28	-------	15	4	50	7	33
19	do	36	1	0	4	16	7	21
Oct. 2	do	24	1	30	1	53	3	17
4	do	28	-------	15	1	[2] 1	1	1
4	do	35	-------	45	-------	[2] 29	-------	29
5	do	24	-------	30	-------	[2] 48	-------	48
6	do	28	-------	30	3	48	9	38
7	Steelhead	31	-------	15	4	2	-------	58
11	Chinook	29	-------	15	?	?	3	46
12	Silver	22	-------	15	4	[2] 53	4	53
13	Chinook	33	-------	15	1	33	3	32
14	do	25	-------	30	-------	32	1	55
15	Silver	24	-------	15	-------	12	1	41

[1] To nearest quarter hour.
[2] Contact lost before fish left release area.

Since observations were limited to a period when there was little current through the release area, the question arises how nearly did the movements observed correspond to fish movements during periods of greater flow. Of the tracked fish, 70% went below the release point; 9 of them came to within 50 feet of the spill gates. We can only guess whether the number would have been greater had a strong current been moving in the direction of the spillway, or whether, with a strong current by which to orient themselves, the fish would have moved more directly upstream and spent less time wandering in the release area.

To determine whether fish being tracked were influenced by motor noises, propeller turbulence, or possibly the sight of the boat, we attempted on several occasions to herd fish that were moving upstream by approaching them from different directions. We were unable to cause a fish to change its course or rate of travel.

Effect of tagging and handling

The degree to which fish were affected by handling and tagging is a matter of conjecture. But we do not believe that the sonic tag, used in a quiet stretch of river such as the Bonneville forebay in September and October, seriously affects the natural behavior of adult salmon. The weight of the tag is probably a neglible factor; 2 grams is the maximum weight in water and most tags are within a fraction of a gram of being weightless. However, the tag does create some drag as it moves through the water. We assumed that large fish are less affected by this than small fish. Therefore, at Bonneville, when a choice of size was possible, we selected fish that weighed an estimated 10 pounds or more. The average estimated weight of all fish tagged was 14 pounds and we did not tag a fish weighing less than 5 pounds.

The hog-ring fastener is a probable source of irritation, but while a more refined device is being sought, the present one allows us to tag quickly without removing the fish from the water or immobilizing it. Of the fish tagged at Bonneville, about one in four reacted to tagging by thrashing about in the live box for several seconds before settling down. Others showed no visible reaction.

Possible effects on the fish from sonic properties of the tag are under investigation. So far, we have seen no response by young or adult salmonids to sounds at or near the tag's carrier frequency level of 132,000 cycles per second, even at sound intensities several thousand times greater than that of the tag. It is more likely that they perceive vibrations set up at the tag's pulsing frequency of 1,000 to 2,000 pulses per second. Burner and Moore (1953), working with trout up to 24 inches in length, subjected them to frequencies ranging from 67 cps. to 70,000 cps. and observed that they "started" momentarily as low frequency sounds were turned on, but showed no response to continued sound. (They observed no response by the fish, initial or otherwise, to ultrasonic frequencies.) This momentary reaction pattern was also observed by Moore and Newman (1956) working with salmon fingerlings within a frequency range of 5 cps. to 20,000 cps. They

TABLE 2.—*Time, distance, and rate of movement of fish tracked beyond release area*

Date	Species	Hour released	Total time fish tracked		Time tracked after fish left release area		Net distance tracked upstream	Average speed after fish left release area	Remarks
		Military time	Hours	Minutes	Hours	Minutes		Miles per hour	
Aug. 8	Steelhead	1114	3	03	2	58	3 miles	1.0	
20	Chinook	1243		56		47	200 yards	.1	
22	do	0856	1	39		59	150 yards	.1	
23	do	1121	2	31		17	250 yards	.5	
29	do	0900	1	10		42	¾ mile	1.1	
29	do	1258	2	00	1	01	1 mile	1.0	
Sept. 3	do	0845	8	45	7	37	10 miles	1.3	See figs. 5 and 10.
4	do	0851	3	49	3	49	6 miles	1.6	See fig. 11.
7	do	0858	6	42	5	53	7 miles	1.2	See fig. 13.
8	do	0831	5	04	3	51	4½ miles	1.2	See fig. 6.
9	do	1112	10	38	9	08	9¾ miles	1.1	See fig. 14. Fish traveled 8¾ miles in 6¾ hours before dark.
10	do	1244		49		29	¾ mile	1.6	
11	do	0851	3	44	2	50	3¼ miles	1.2	
13	do	1102	16	43	13	46	5 miles	.4	See figs. 8 and 12. Fish traveled 4½ miles in 5¼ hours before dark.
18	do	1122	7	33	2	43	250 yards	.1	See fig. 7. Fish entered Eagle Creek 1620 hours and was there 2½ hours later when tracking was abandoned at dark.
19	do	1004	7	21	3	05	1¾ miles	.6	
Oct. 2	do	1325	3	17	1	24	¾ mile	.5	
6	do	1140	9	38	5	50	½ mile	.1	Fish traveled ½ mile in 3 hours before dark;
7	Steelhead	1236	5	00		58	400 yards	.2	Fish made no sustained movement upstream.
11	Chinook	1046	3	46			1 mile	?	Lost contact with fish for 3 hours; fish left release area sometime during this period.
13	do	0919	3	32	1	59	3¾ miles	1.9	
14	do	1149	1	55	1	23	2 miles	1.5	
15	Silver	1246	1	41	1	29	1 mile	0.7	

concluded, as did Burner and others, that after the initial "start" the fish quickly adjusted to the new sound and accepted it as part of the large volume of noise normally encountered in the environment. We think it likely that this may also be true with any perceptible sound from the sonic tag.

In a tagging study of this sort, when movements of fish can be measured only over a period of hours rather than days, weeks, or months, any effect from handling a fish prior to release is magnified in the results. We therefore took special care to excite the fish as little as possible. In the dipnet transfer from floating trap to live box they were out of the water a maximum of 5 seconds. Tagging was done while the fish were completely under water and unconfined within the limits of the live box. Although it was unnecessary at any time to place our hands on the fish or in the water, rubber gloves were worn as an extra precaution against the effect of human odor on natural behavior. Finally, the sliding-gate arrangement allowed tagged fish to swim freely out of the live box. In spite of these measures some effect was inevitable but extremely difficult to determine in the field. This problem is therefore being investigated further at the Fisheries-Engineering Research Laboratory[1] and the Seattle Biological Laboratory[2] fish behavior facilities.

SUMMARY

1. Thirty-nine Columbia River salmon and four steelhead trout were tagged with miniature sonic transmitters at Bonneville Dam in 1957 and were tracked one at a time. Sound waves from the sonic tag were picked up by an automatic homing receiver mounted in a boat. Data were plotted on charts as a continuous record of individual movements of fish in the Columbia River.

2. All fish were released in the dam forebay near the exit of the Washington-shore fish ladder. The time individual fish took to move out of the release area ranged from less than a minute to nearly 5 hours; the average time was 1½ hours.

3. Seventy percent of the fish traveled some distance downstream from the release point. Nine moved to within 50 feet of the spillway.

[1] Redesignated North Bonneville (Wash.) Field Station, U.S. Bureau of Commercial Fisheries, January 1959.

[2] Seattle Biological Laboratory, U.S. Bureau of Commercial Fisheries, Seattle, Wash.

4. In the release area fish spent more than 90 percent of a total of 47 hours swimming within 50 feet of shore. They seldom left the shoreline for more than 2 minutes at a time.

5. Of 23 fish tracked for some distance above the release area, only 3 crossed to the Oregon shore. One crossed 6 miles above the dam, the other two at Bradford Island.

6. Individual fish were tracked as far as 10 miles upstream and for periods as long as 16¾ hours.

7. After the fish left the release area, they rarely swam in water more than 30 feet deep. Where the bottom dropped sharply, fish followed the shoreline closely. Through broad shallow areas individual courses varied more.

8. During hours of daylight fish moved over the bottom at an average rate of approximately 1.5 miles per hour against current ranging in velocity from less than ¼ foot per second to 2 feet per second; their net rate of movement upstream was 1.2 miles per hour.

9. Fish stopped and dropped back frequently where they encountered log rafts tied alongshore. Otherwise, they usually maintained a steady rate of movement after leaving the release area.

10. Each of three fish tracked from daylight into darkness either slowed its pace or came to a complete halt as it grew dark.

LITERATURE CITED

BURNER, CLIFFORD J., and HARVEY L. MOORE.
1953. Attempts to guide small fish with underwater sound. U.S. Fish and Wildlife Service, Special Scientific Report–Fisheries No. 111, 38 pp.

MOORE, HARVEY L., and H. WILLIAM NEWMAN.
1956. Effects of sound waves on young salmon. U.S. Fish and Wildlife Service Special, Scientific Report–Fisheries No. 172, 19 pp.

TREFETHEN, PARKER S.
1956. Sonic equipment for tracking individual fish. U.S. Fish and Wildlife Service, Special Scientific Report–Fisheries No. 179, 11 pp.

TREFETHEN, PARKER S., J. W. DUDLEY, and M. R. SMITH.
1957. Ultrasonic tracer follows tagged fish. Electronics 30(4): 156–160. April.

U.S. GOVERNMENT PRINTING OFFICE : 1960 O—540524